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Research on Safety Services Capability Model for ATC service in ATM Division

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Abstract

Based on the differences of operation characters between ATC service and manufacturing industry, this paper researched the implication of safety services capability of ATC service by combining the latest implication of process capability and safety. And this paper established the elemental composition system made of safety services capability of ATC service, which is composed of 4 second-level elements and 15 third-level index. The 4 second-level index includes personnel capability, equipment capability, environmental capability and management capability. Considering the fuzziness of each index, the value of services capability of ATC service was confirmed by fuzzy-matter-element analysis method and entropy weighting method. With evaluating ATC service of ATM division by this safety services capability model, it was indicated that this ATM division possessed strong safety services capability, personnel capability. Equipment capability was stronger than environment capability. It was conformed to the fact. The evidences showed that this safety services capability model for ATC service is practical, feasible, and conformed to the level of actual safety services capability of ATC service.

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Keywords: ATC service; fuzzy-matter-element analysis method; safety services capability

1.Introduction

Recently, with the rapid development of civil aviation industry and the increase of flight number, finite air route resource cannot meet the need of air traffic, which just like finite road resource cannot meet the traffic on land. Therefore given the condition that route cannot be increased easily, the enhancement of utilization rate and passing rate of route is very important. As for civil aviation industry, enhancement of the capability of ATC service in ATM division is the only feasible method to solve the ″ bottleneck″ in current situation of civil aviation transportation. However, current civil aviation industry just restricts the ″ Minimum Separation″ , ″ personnel qualification″ and ″ job specification″ and so on in the ″ rule″

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of ATC. The assessment of ATC is just restricted by safety index such as accident rate (including accident symptom). That kind of situation created a possibility that on the purpose of achieving ″ safety index″ , some ATM divisions or air traffic controllers adopt several decreasing ATM operation capability ″ measures″ , which make use of the leaks of ″ rule″ only limiting the minimum margin, such as enlarging separation, controlling flow, to enhance safety margin and achieve safety goals. Obviously, it does harm to the harmony and development of civil aviation industry. Nevertheless, the ″ services capability″ of ATC service in ATM division depends on composite result of several factors such as the number and quality of personnel and equipment, the level of management. When the personnel capability is not sufficient, the only result of requiring decreasing separation and increasing work load is causing the mismatch between capability and job requirements, furthermore making serious accident. Therefore, how to assess the ″ safety services capability″ of ATC service in ATM division and then define the relevant capability standard are very important.

Currently, there is no sufficient research on safety services capability of ATC service at home or abroad, several scholars had defined the safety capability from several aspects such as personnel and organization. According to the characters of construction workers, Wang Panpan[1]gave definition of safety services capability that in construction field, constructor utilizes and integrates knowledge, skills, attitudes, motivations, personal values and other internal characteristics of the construction workers to make hazards, existing in a process of construction, under absolute control minimum limits, or at least be kept in allowable range. And in that paper, influence factors of constructor safety services capability had been analyzed from three aspects such as personnel factors, organizational factors and safety factors of work. However, in that paper, the definition and model of safety capability mainly focused on safety capability of personnel but were not suitable for safety services capability of ATC services. Focusing on the relationship between safety resource capability and organization safety capability in the process of organization operation, Ma Jiye[2]proposed that organization safety capability refers that energy, transformed from safety knowledge resource which is abstracted from various safety resources, acts on various safety resource process. According to different characters of various safety resources, safety capability (resultant force) can be decomposed into corresponding safety capability (component force). And established the model of organization safety capability from 6 aspects such as financial, practicality, manpower, technique, reputation, organizational safety component force(resource). However, in this model, the safety implication is applicable to occupational health safety in manufacturing industry, but not to aviation safety in civil aviation industry, which is the core element of civil aviation enterprise and public institution such as airline company, ATM, aerodrome and so on. Therefore, based on the results of previous studies, drawing on the international definition of capability, process capability and safety, combined with the implication of ATC service in ATM division, this paper established the safety services capability model of ATC service in ATM division.

2.Definition of Safety Services Capability of ATC Service

In GB/T19000-2008 Quality management systems — Fundamentals and vocabulary, capability is divided into organization capability, system capability, process capability and personnel capability. Capability of organization, system and process refers to the ability of that organization, system and process to implement product and meet requirement[3]. In GB/Z 19027-2005 Guide of statistical technique of GB/T 19001-2000, process capability analysis is defined as inherent variability and distribution in checking process, and then estimated the output capability of the variation that meets the specifications allowed by range[4]. International Civil Aviation Organization (ICAO) defined safety as a kind of state that through ongoing hazard identification and safety risk management process, the possibility of personal injury or property damage will be reduced and maintained under an acceptable level[5]. In Rules of Civil Aviation Air Traffic Management, the requirement of ATC service is to avoid collision of aircrafts or aircrafts and obstacles in maneuvering area, and to maintenance and speed up the ordered flow of air traffic[6].

Therefore, integrating the definition of process capability, safety and ATC service, the ATC service safety services capability in ATM division is defined as the maximum service level of ATC service in this paper. The purpose of ATM division is to avoid collision of aircrafts or aircraft and obstacles in maneuvering area, and to maintenance and speed up the ordered flow of air traffic, which is under the precondition of ensuring the risk in the process of ATC service at the acceptable level or less.

3.System of ATC Service Safety Services Capability Index

According to the definition of ATC service safety services capability, this paper established the second-level index system of safety services capability by 4 aspects, whichare personnel capability, equipment capability,environment capability and management capability. Furthermore each second-level index is specified into third-level (see fig- 1).The level of third-level index can be divided into 3 grade which are excellent, medium and poor. The value ranges 100-80 is considered as excellent, 79-60 is considered as medium and 59-0 is considered as poor.

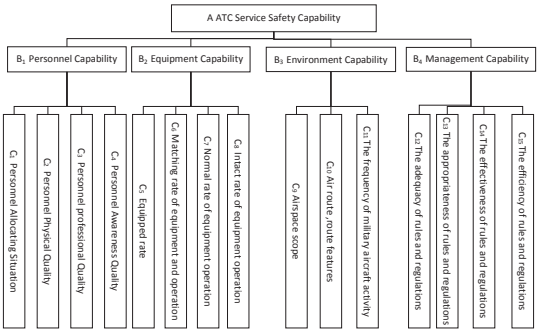

Figure 1. ATC service safety services capability index system

4.Fuzzy-matter-element Evaluation of ATC Service Safety Services Capability

Owing to the fuzziness of Safety Services of ATC service, this paper set″ATC service capability, second (third)-level evaluation index, index level ″as matter-element, andchosen fuzzy-matter-element analysis method which have an advantage on processing fuzzy incompatibleinformation to evaluate safety services capability of one ATM division.

4.1.Fuzzy-matter-element to determine the safety capability of ATC service

Through actual value judge of objective index, such as the equipped rate, the matching rateof equipment and operation of control operations of a ATM division. Through Delphi Method the experts score the size of the subjectiveindex, such as professional quality and awareness qualityof the staffs.(See Table I)

TABLE I. THIRD-LEVEL INDEX VALUE OF SAFETY CAPABILITY

C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
75	86	90	84	80	72	95	96	65	62	44	93	61	65	69

When measuring more frequently or using the Delphi method many times, the value of third-levelindex X of the control operations can be approximately considered as normal type [7] as u(x) to the same class membership function that:

$$u(x) = \exp\left[-\left(\frac{x-p}{q}\right)^2\right] \text{in which,}$$
$$p = \frac{a+b}{2},\ \ q = \frac{|a-b|}{1.665} \quad (1)$$

Take the third-index values in table 1 into(1),get the corresponding degree membership u (x),of which the second level evaluation index B corresponding to the third level evaluation index fuzzy-matter-element, then get fuzzy-matter-element matrix $R_{15\times3}$of safety capabilities of each index ,table II.

TABLE II. THIRD-LEVEL INDEX MEMBERSHIP OF SAFETY CAPABILITY

Third-level evaluation index C	excellent	medium	poor
Personnel Allocating situation C_1	0.2103	0.7927	0.1923
Personnel physical qualityC_2	0.8950	0.1236	0.0787
Personnel professional quality C_3	1.0000	0.0397	0.0542
Personnel awareness quality C_4	0.7792	0.1990	0.0939
equipped rate C_5	0.5000	0.4289	0.1312
matching rate of equipment and operation C_6	0.1059	0.9531	0.2373
Normal rate of equipment operation C_7	0.8409	0.0068	0.0328
Intact rate of equipment operation C_8	0.7792	0.0045	0.0295
Airspace rangeC_9	0.0131	0.8560	0.3665
Air route ,route featuresC_{10}	0.0044	0.6492	0.4312
The frequency of military aircraft activityC_{11}	0.0000	0.0068	0.8458
The adequacy of rules and regulationsC_{12}	0.9395	0.0144	0.0403
The appropriateness of rules and regulationsC_{13}	0.0029	0.5742	0.4537
The effectiveness of rules and regulationsC_{14}	0.0131	0.8560	0.3665
The efficiency of rules and regulationsC_{15}	0.0471	0.9981	0.2886

4.2.Apply entropy value method[7] to determine the weight

Apply entropy value method to determine the weight of each third-level evaluation index. Standardize each third-level evaluation index membership determined in table II, get y_{ij},the results can be seen in table III.

TABLE III. THIRD-LEVEL EVALUATION INDEXY_{IJ}

third-level evaluation index C	**excellent**	**medium**	**poor**
C_1	0.1759	0.6632	0.1609
C_2	0.8157	0.1126	0.0717
C_3	0.9142	0.0363	0.0496
C_4	0.7268	0.1856	0.0876
C_5	0.4717	0.4045	0.1238
C_6	0.0817	0.7353	0.1831
C_7	0.9550	0.0077	0.0373
C_8	0.9581	0.0056	0.0363

C_9	0.0106	0.6927	0.2966
C_{10}	0.0040	0.5985	0.3975
C_{11}	0.0000	0.0080	0.9920
C_{12}	0.9450	0.0145	0.0405
C_{13}	0.0029	0.5570	0.4402
C_{14}	0.0106	0.6927	0.2966
C_{15}	0.0353	0.7483	0.2164

Each Entropy weightings(see Table IV) of all the third-level evaluation elements to second-level evaluation elements are worked out by$w_i = \frac{1-e_i}{\sum_{i=1}^{n}(1-e_i)}$,inwhich $e_i = -k\sum_{i=1}^{n} y_{ij}\ln(y_{ij})$. And the entropy weightings of that to the safety ensuring capability of ATC also can be seen in Table V.

TABLE IV. ENTROPY WEIGHTINGS OF ALL THE THIRD-LEVEL EVALUATION ELEMENTS TO SECOND-LEVEL EVALUATION ELEMENTS

Person capability		Instrument capability		Environment capability		Management capability	
C_1	0.1250	C_5	0.0524	C_9	0.2304	C_{12}	0.4034
C_2	0.2745	C_6	0.1567	C_{10}	0.2129	C_{13}	0.1865
C_3	0.4124	C_7	0.3925	C_{11}	0.5567	C_{14}	0.2058
C_4	0.1881	C_8	0.3984			C_{15}	0.2043

TABLE V. ENTROPY WEIGHTINGS OF ALL THE THIRD-LEVEL EVALUATION ELEMENTS TO THE SAFETY ENSURING CAPABILITY OF ATC

C_1	0.0280	C_6	0.0441	C_{11}	0.1299
C_2	0.0614	C_7	0.1105	C_{12}	0.1054
C_3	0.0923	C_8	0.1121	C_{13}	0.0487
C_4	0.0421	C_9	0.0538	C_{14}	0.0538
C_5	0.0148	C_{10}	0.0497	C_{15}	0.0534

4.3.Fuzzy Matter Element Evaluation of the safety ensuring capability of ATC Service

- Fuzzy Matter Element Evaluation of Personnel capability, Instrument capability, Environment capability and Management capability of which ATC is consisted.

Relevancy Matter Elements of ATC Personnel capability, Instrument capability, Environment capability and Management capability are worked out by $M(\cdot,+)$mathematical operation, which is to take multiplication then addition, with Matter Elements relevant to Personnel capability, Instrument capability, Environment capability and Management capability of Fuzzy Matter Element matrix$R_{15\times3}$, acquired by Table II, and elements in Table IV, $M(\cdot,+)$mathematical operation. As is shown in followings:

Relevancy Matter Elements of ATC Personnel capability：

$$R_{Personnel\ capability} = [\text{excellent } 0.8309 \ \ \text{medium } 0.1868 \ \ \text{poor } 0.0857] \quad (2)$$

Relevancy Matter Elements of ATC Instrument capability：

$$R_{\text{Instrument capability}} = [\ \text{excellent } 0.6833 \ \ \text{medium } 0.1763 \ \ \text{poor } 0.0687] \quad (3)$$

Relevancy Matter Elements of ATC Environment capability：

$$R_{\text{Environment capability}} = [\ \text{excellent } 0.0040 \ \ \text{medium } 0.3392 \ \ \text{poor } 0.6471] \quad (4)$$

Relevancy Matter Elements of ATC Management capability：

$$R_{\text{Management capability}} = [\text{excellent } 0.3919 \ \ \text{medium } 0.4929 \ \text{poor } 0.2353] \quad (5)$$

It can be seen from formula(2)-(5)： In this ATC unit, Personnel capability and Instrument capability are holding the highest Relevancy to ″excellent″， Environment capability is holding the highest Relevancy to″poor″, Management capability is holding the highest Relevancy to ″medium″. Therefore, Personnel capability and Instrumentcapability is″excellent″ , Management capability is″medium″， and Environment capability is″poor″.

- *Composite Fuzzy Matter Element Evaluation of ATC services safety* ensuring *capability*

Relevancy Matter Element of ATC services safety ensuring capability is worked out by $M(\cdot, +)$mathematical operation, which is to take multiplication then addition, with Fuzzy Matter Element Matrix $R_{15\times3}$ and Entropy weightingMatter Element R_{W_i}, acquired from Table Ⅱ， As is shown in followings：

ATC services Relevancy Matter Element：$R_{\text{ATCservices}}$

$$= [\text{excellent } 0.4816 \ \ \text{medium } 0.3 \ \ \text{poor } 0.251] \quad (6)$$

It can be seen from formula(6)：The highest Relevancy means that ATC services safety ensuring capability of this ATC unit is ″excellent″, whose value is 0.4816. Then the second highest Relevancy means ″medium″ whose value is 0.3. Therefore, ATC services safety ensuring capability of this ATC unit is ″ excellent″ partially ″medium″, which is correspond to the matter of the fact.

5.Conclusion

- ATC services safety ensuring capability is defined as the highest level (or ability) of service that performs to avoid collision of aircrafts or aircrafts and obstacles in maneuvering area, to maintenance and speed up the ordered flow of air traffic, and to ensure the safety risks of ATC services are controlled under an acceptable level.
- ATC services safety ensuring capability index system is established. The system consists of 4 second-level index, which are Personnel capability, Equipment capability, Environment capability and Management capability. Furthermore, Personnel capability consists of 4 third-level index: Personnel Allocating Situation, Personnel Physical Quality, Personnel Professional Quality and Person Awareness Quality; Instrument capability also consists of 4 third-level index: Equipped rate, Matching rate of equipment and operation, Normal rate of equipment operation and Intact rate of equipment operation; Environment capability consists of 3 third-level index: Airspace scope, Airline/route features and Military aircraft activity; Management capability consists of 4 third-level index: the adequacy of rules and regulations, the appropriateness of rules and regulations, the effectiveness of rules and regulations, the efficiency of rules and regulations.
- Considering the fuzziness of each index, the value of services capability of ATC service was confirmed by fuzzy-matter-element analysis method and entropy weighting method.
- With evaluating ATC service of ATM division by this safety services capability model, it was indicated that this ATM division possessed strong safety services capability, personnel capability. Equipment capability was stronger than environment capability. It was conformed to the fact.
- The evidences showed that this safety services capability model for ATC service is practical, feasible, and conformed to the level of actual safety services capability of ATC service.

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